

The study of ground-level ozone in Kiev and its impact on public health

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Abstract

Ground-level ozone in Kiev for an episode of its high concentration in August 2000 was simulated with the model of the urban air pollution UAM-V (Urban Airshed Model). The study of total ozone over Kiev and its concentration changes with height in the troposphere is made on the basis of ground-based observations with the infrared Fourier spectrometer at the Main Astronomical Observatory of National Academy of Sciences of Ukraine as a part of the ESA-NIVR-KNMI no 2907. In 2008 the satellite Aura-OMI data OMO3PR on the atmosphere ozone profiles became available. Beginning in 2005, these data include the ozone concentration in the lower layer of the atmosphere and can be used for the evaluation of the ground-level ozone concentrations in all cities of Ukraine. Some statistical investigation of ozone air pollution in Kiev and medical statistics data on respiratory system was carried out with the application of the “Statistica” package. The regression analysis, prognostic regression simulation, and retrospective prognosis of the epidemiological situation with respect to respiratory system pathologies in Kiev during 2000–2007 were performed.

Key words: Earth atmosphere; ground-level ozone; health effect

1 Introduction

Simulation of ground-level ozone concentrations in Kiev for an episode of its high concentration in August 2000 [3, 10, 11] is performed using a model of urban air pollution UAM-V [12]. A study of total ozone over Kiev and its concentration changes with altitude in the troposphere was also carried out using ground-based observations with the infrared Fourier spectrometer at the Main Astronomical Observatory of the National Academy of Sciences of Ukraine (MAO NASU) as a part of the ESA-NIVR-KNMI project no 2907 “OMI validation by ground based remote sensing: ozone columns and atmospheric profiles (2005–2008)” [7, 8, 9].

Ground-level ozone is a highly toxic gas relative to humans and all living matter. It is formed in photochemical reactions of precursors exhausted mainly by vehicles and large industrial plants. In fact, it is an indicator of anthropogenic pollution of the studied areas [6, 10, 14, 15].

Ozone was revealed by Schonbein in 1840 and almost immediately its concentration was began to measure at the Pic du Midi in France. A long series of mountain observations from 1870 to the present day showed the increase in background ozone concentrations in air, from 10 ppb (parts per billion by volume) to 50 ppb. This last value is now recommended by the World Health Organization (WHO) as the maximum allowable 8-hour ozone concentration [15]. Today, the 2171 ozone monitoring stations are officially registered in the monitoring network of Europe [1]. The stations are of different types: urban, rural and background, including 2111 stations in EU countries. The greatest number of stations are located in the countries such as France (439), Spain (367), Germany (286), Italy (235). In the Czech Republic there are 71 stations, in Poland are 68, in Romania are 27, in Latvia are 6, in Lithuania are 15, and in Estonia are 7 stations. At the same time in Ukraine, we do not have any ozone monitoring stations registered officially in the aforementioned European network. Our metrological service does not have calibration instruments for measuring ozone with gas analyzers. However, ozone pollution in Ukraine (Kiev, the Carpathians) and its effect on plants was studied in the papers [2, 4] since 1996.

Intensive study of the ozone chemistry and harmful effect of ozone on human health and crops began after 40% crop losses in Europe in 1940. Ozone is formed by the reaction: $O + O_2 + M \equiv O_3 + M$, where M is molecule-catalyst, such as N_2 . In the urban atmosphere the oxygen atom is formed from nitrogen oxides, $NO_x(NO_2 + NO)$ by photochemical reaction under the influence of solar radiation with wavelengths less than 424 nm (a wavelength less than 290 nm is delayed in stratospheric ozone layer at an altitude of 20–35 km above land): $NO_2 + h\nu \equiv NO + O$. But again, NO is oxidized by ozone to NO_2 , so the accumulation of ozone in this cycle does not occur. There must be another way of oxidation of NO to NO_2 and it was found. There are peroxide radicals which are formed by oxidation of volatile organic compounds both natural and anthropogenic origin: $NO + RO_2 \cdot \equiv NO_2 + RO \cdot$, where R is any organic fragments such as C_2H_5 .

As chemical and toxic substance the ozone has been well studied [14, 15]. As for its effect on the health of the inhabitants of modern cities, this question in Ukraine is only beginning to study in contrast to the United States and European countries (see, e.g., [5, 13, 14, 15, 16]). In Ukraine this problem requires the most careful consideration: firstly, because of the complexities of economic, medical and environmental conditions prevailing in recent years, and secondly, because there is a high transformation of cities into modern metropolises with a huge flows of vehicles. This phenomenon is new from many points of view and it has not yet been studied, including health and environmental aspects.

The main goal of this work is to carry out a retrospective study of the influence of ozone on the human health in Kiev, the capital of Ukraine, since 2000. Unfortunately, we do not yet have the Health Statistics (HS) data for 2008–2010.

It is known that ozone is air pollutant of the first class of danger according to the action on human and animal health, plants and building facilities. The main tagits of ozone action on human health are the respiratory system (RS) and cardiovascular system (see, for example, [5, 6, 16]). Our purpose is the study and validation of forecasting of the connection between ozone concentrations in Kiev and the state of the respiratory system of the city population. It is expected to use the results of this study to assess the risks of harmful effects of ozone on the health of the inhabitants of Kiev and other cities of Ukraine as at the population and individual (personal) levels. Note very high summertime concentrations of ozone in Odessa city (up to 200 ppb), given by the simulation by EURAD prognostic system of the Rhenish Institute for Environmental Research at the University of Cologne (<http://www.eurad.uni-koeln.de>).

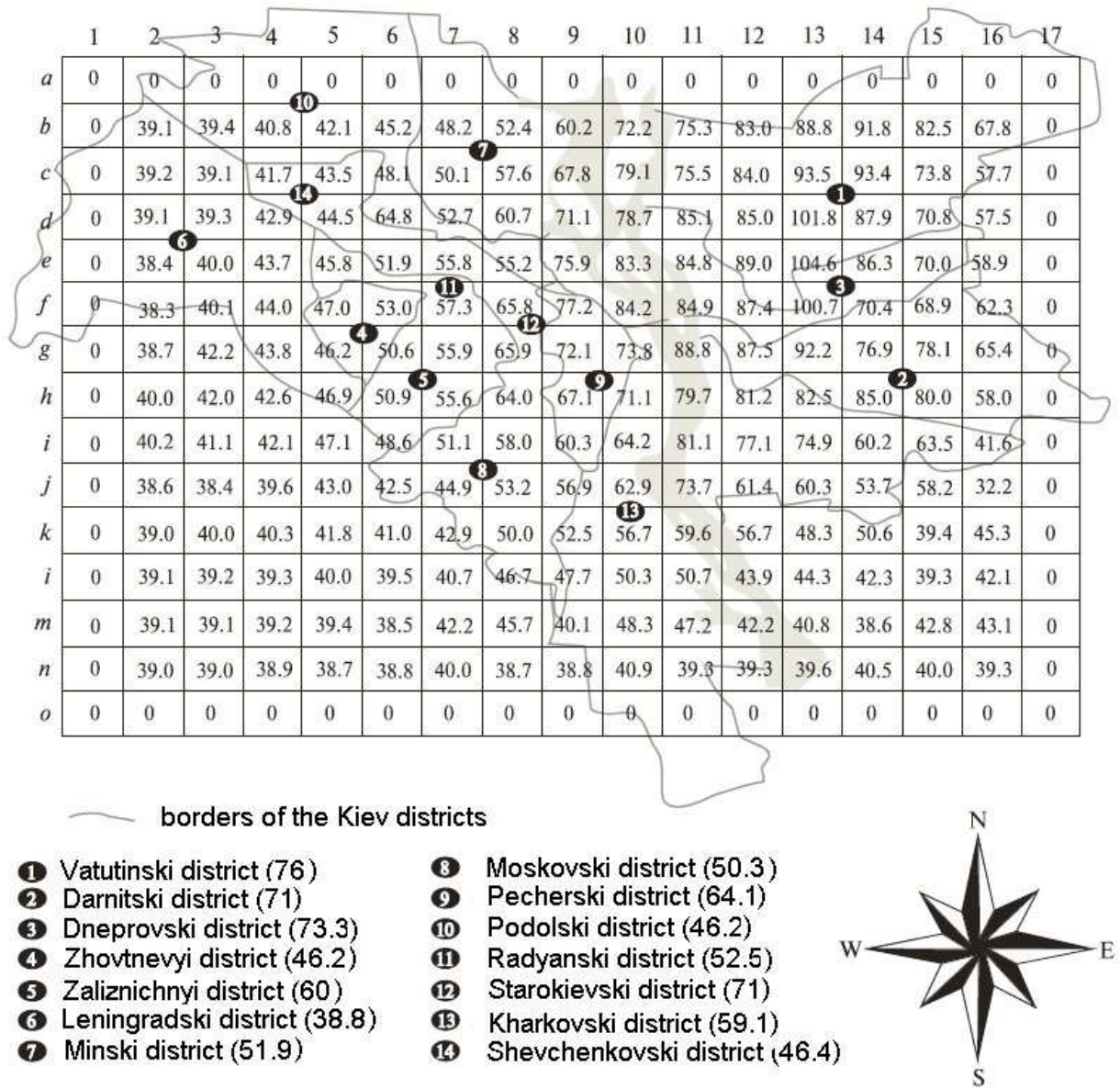


Figure 1: Distribution of mean maximal ozone concentrations in Kiev derived from the modelling. Average ozone concentration in each Kiev district is given in brackets. The ozone concentrations are given in ppb.

2 Materials and methods

To perform the planned work we used the statistical data of the City Department of Health (CDH) and the Ministry of Health (MH) for the period 2000–2007 years. The data contains 12 indicators determining the overall and primary morbidity of ozone dependent RS pathologies for the population of 14 Kiev districts. These data related to five socio-age groups of Kiev’s inhabitants: children, teenagers, adults, working age, and pensioners. Figure 1 shows the averaged maximum ozone concentration for 14 districts of Kiev as well as for Kiev as a whole for the “ozone episode” in August 2000. These data were obtained by the simulation of the ozone pollution taking into account the ozone formation processes and scattering of ozone forming matter in the surface layer of the atmosphere over the city [10, 11]. In the simulation the UAM-V model [12] was used taking into account the following factors: the relief of the city, weather conditions, the intensity of solar radiation, the number of volume and point emissions to the atmosphere by industrial enterprises, the number of vehicles in the city, the speed of

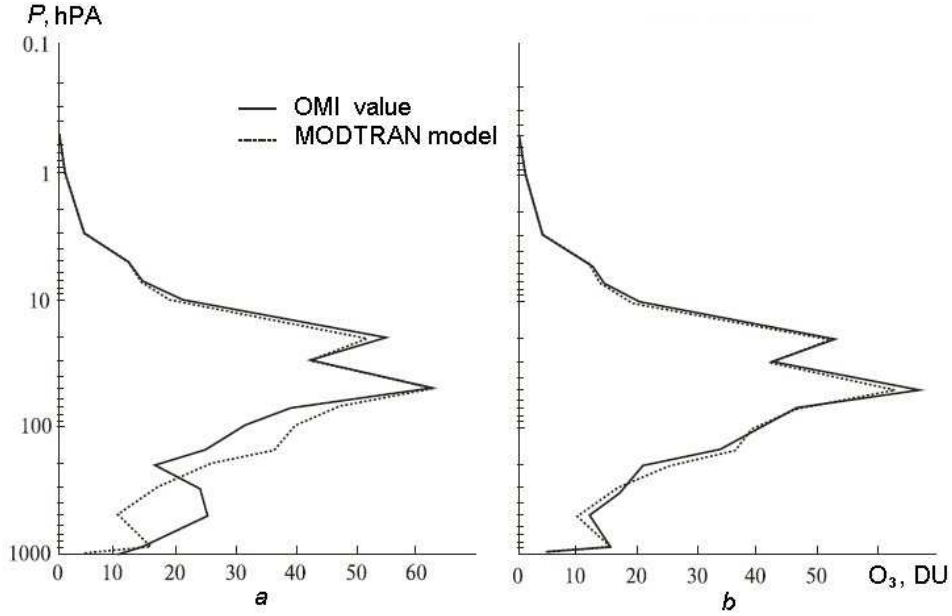


Figure 2: Comparison of the atmospheric ozone profiles derived from the OMI data (OMO3PR) of version 2008 (a) and version 2009 (b) with our atmospheric ozone profile (April 23, 2007) retrieved by MODTRAN modelling. Ozone concentrations are expressed in the summary quantities for each of the 18 atmospheric layers defined by the OMO3PR data.

traffic flows.

The satellite Aura-OMI data on the atmosphere profiles of ozone concentration OMO3PR (http://disc.sci.gsfc.nasa.gov/Aura/data-holdings/OMI/omo3pr_v003.shtml) have appeared in 2008. They include ozone data for the lower layer of the atmosphere beginning in 2005. We performed a comparison of these ozone profiles for Kiev and the profiles recovered by us from the infrared Fourier spectrometer observations and modelling with MODTRAN4 code [7, 8, 9]. The first comparison of our retrieved profile for April 23, 2007 with OMO3PR data showed a significant difference in tropospheric part of the profiles (Fig. 2a). However, the profile of new version of OMI data in 2009 is in good agreement with our profile for the same date (Fig. 2b). This is a good reason for using OMI data in evaluating ground-level ozone concentrations in all cities of Ukraine.

Statistical study of available data was carried out using the software package “Statistica” (e.g., http://softnic.ru/soft/programm_4456.html). It included a correlation analysis of the Kiev district data on ozone pollution and the RS state data averaged in each district of the city. In such way we obtained the correlation coefficients between the compared values, performed a regression analysis, and constructed predictive regression models.

3 An epidemiological study of the ground-level ozone impact on the RS state of Kiev population in 2000

The first epidemiological study of the ozone problem in Ukraine was carried out using our modelling of ozone concentrations in 2000 [6]. At that time, the administrative structure of Kiev included 14 districts. Each district was served by a network of district clinics supplying statistics data in Kiev centre “Medinstat”. This gave the opportunity for a full statistical comparison of averaged district RS indicators of the city population and averaged maximum district ozone

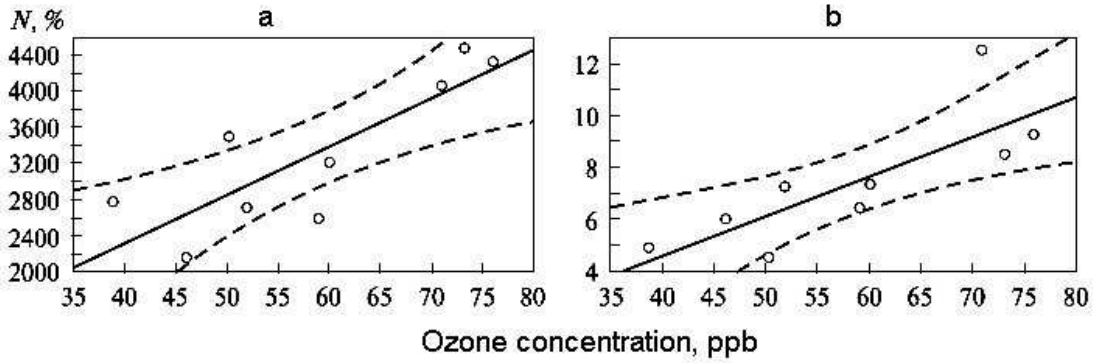


Figure 3: The prevalence (N) of respiratory diseases of the adult population per 100 000 (a) and asthmatic bronchitis of children per 1000 children (b) with average ozone concentrations for the "sleeping" districts of Kiev. The dashed curves show the confidence level of 95 percent.

concentrations calculated by the modelling code UAM-V [12] (Fig. 3). The correlation study showed for the socio-aged group "adults" (it is more than 70% of the population) statistically significant relationships emerged in terms of "respiratory diseases" and "pneumonia". For socio-aged group "children" a statistically significant correlation was revealed in terms of "asthmatic bronchitis" ($r = 0.66$). The correlation between asthma in children group and peak ozone concentrations was studied, for example, in the paper [13].

When selecting from the investigated city districts the nine suburban "bedroom" districts (Vatutinsky, Darnytskyi, Dnieper, Zhovtnevyi, Zaliznichnyi, Leningrad, Moscow, Kharkov and Radyanskyi) with their socio-economic, medical, and ecological features, and with their almost the same population density (five thousand people per 1 km²), we found a high correlation between ozone concentrations and medical data. For adults the value of correlation $r = 0.83$, for children $r = 0.80$ (Fig. 3). Further, taking into account the observed correlations we carried out regression analyses of the examined data. The linear regression equation were built to predict the state of the RS of the Kiev residents in terms of "respiratory diseases" (RD) for adults and "asthmatic bronchitis" (AB) for children depending on the annual peak concentrations of ozone in their districts.

A prognostic study of the epidemiological situation with respect to RD pathologies in Kiev in 2002–2006 was carried out with the involvement of ground-level ozone measurements obtained at the N.N. Grishko National Botanic Garden of the National Academy of Sciences of Ukraine, the satellite data (Aura-OMI), as well as the modeled ozone concentrations for Europe (including Ukraine) obtained by of the Rhenish Institute for Environmental Research at the University of Cologne. We assumed that these data characterize the ozone concentrations averaged over city in 2000–2007. On the base of these data we forecasted the overall incidences of respiratory diseases (adults), and asthmatic bronchitis (children).

Comparison of the results of prediction and health statistics for 2000–2007 in Kiev (Table) showed that forecasts constructed on the simulation results, in general, was confirmed. Thus, the correlation coefficient for "Respiratory Diseases" (adults) was 0.76 for the ozone concentrations according to the simulation and 0.72 for the data obtained by UV-ozone analyzer (TECO-49C). According to satellite data Aura-OMI (2005–2007) for the same indicators were obtained sufficiently close to the actual values of assessing the incidences of pathologies of RS. Note also that if for the central and southern Europe the peak ozone concentrations occurred in 2003 followed by a slight decrease, then for Eastern Europe this did not happen probably due to the increase of road transport with old systems of fuel combustion, which are prohibited in the EU countries.

It should be noted that the World Health Organization (WHO) [15] pointed out as espe-

Table. Surface ozone impact on diseases of the respiratory system of population in Kiev during 2000–2007. Comparison of the predicted respiratory system diseases with the medical statistics (MS) data. Error of the prognoses is given in brackets

data source	2000	2001	2002	2003	2004	2005	2006	2007
Ozone concentration (ppb)								
Rhenish model	–	–	75.0	75.0	55.0	78.5	71.5	90.5
Ozonometer	56.9	74.4	75.5	71.1	67.9	84.2	77.0	91.5
Aura-Omi	–	–	–	–	–	63.0	61.9	74.0
Respiratory diseases								
MS data	2996	3093	3236	3534	3391	3561	3600	3836
(per 100 000 adults)								
Prognoses with	–	–	3886	3884	2902	4058	3714	4649
Rhenish model			(20%)	(10%)	(14%)	(14%)	(3%)	(21%)
Prognoses with	2996	3857	3911	3694	3537	4339	3985	4669
Ozonometer		(25%)	(21%)	(4.5%)	(4.3%)	(22%)	(11%)	(22%)
Prognoses with	–	–	–	–	–	3295	3241	3837
Aura-Omi	–	–	–	–	–	(7%)	(10%)	(0.003%)
Asthmatic bronchitis								
MS data	7.37	8.39	8.75	9.2	7.12	9.2	8.75	–
(per 1000 children)								
Prognoses with	–	–	9.7	9.7	9.3	10.1	9.0	–
Rhenish model			(11%)	(5.4%)	(24%)	(11%)	(3%)	
Prognoses with	7.69	9.9	11.	9.2	8.8	10.9	9.95	–
Ozonometer	(4%)	(18%)	(26%)	(0.0%)	(6%)	(18%)	(14%)	–
Prognoses with	–	–	–	–	–	8.8	8.3	–
Aura-Omi	–	–	–	–	–	(8%)	(5%)	–

cially dangerous for human health the four air pollutants: particulate matter, ozone, nitrogen dioxide, and sulfur dioxide. If ozone directly increases the risk of RS diseases, the other three pollutants increase the effect of ozone. As products of vehicle and industrial enterprises emissions they also participate in the ozone formation as its precursors. In [5] it was reported a significant strengthening of the ozone effects on the functional changes in the health of people in conjunction with other adverse environmental factors. The recommendations of the WHO in 2005 [15] lowered maximum 8-hour average concentrations of surface ozone from 60 to 50 ppb (120 to 100 mg m^{−3}) due to the completion of knowledge of the impact of ozone on health in epidemiological studies.

We calculated the root-mean square error σ of one prediction for each row in Table. For “respiratory diseases” of adults it was 15.0% according to the simulation of ozone concentrations and 16.5% according to the ozone measurements. According to the rule 2σ (i.e. 95% probability) we can assume all prognostic values as significant ones. The correlation coefficient of medical statistics data and forecasts according to ozonometer was 0.78. For diseases of asthmatic bronchitis for children standard errors of forecast is 12.46% on the base of the simulation and 14.98% according to ozonometer data.

Thus, we can assume all prognostic values as significant at the specified forecast accuracy. Correlation coefficient of health statistics for asthmatic bronchitis in children and forecast with ozonometer data was 0.76. Note that the average ozone concentration for the city of Kiev based on the modelling (UAM-V) for ozone episode in 2000 coincided with the value obtained by UV-ozone analyzer at the National Botanical Garden. Therefore, the use of the measured

concentrations of ground-level ozone as the average values for the city is justified for predicting RS diseases.

Table shows that almost all the forecast data obtained on the base of the Rhenish model and the ground-based ozonometer data exceed the health statistics data. There can be several reasons and among them there are the reducing number of appeals to district health centers (one part of the population prefers to be treated in private clinics, and the other, needy, is self-treated). Also it is appeared more effective medications, in particular, for allergic asthmatic bronchitis.

4 Conclusion

The problem of forecasting of individual risk of the ground-level ozone harmful impact on human health is particularly acute in Ukraine, since the effective response from government agencies to environmental problems tend to lag far behind the needs of the population.

Our results suggest that the establishment of a monitoring network of ground-level ozone measurements in the cities of Ukraine, expanding the database with respect to ground-level ozone pollution of the atmosphere of Ukraine cities, as well as the statistical base for health and specific diseases of the population of these cities is a necessary condition for the study of harmful effects of ozone on human health in Ukraine. As a result of this work it became apparent that the modelling of ground-level ozone in urban areas should be repeated at least every 3–4 years to search for correlations between the ozone concentrations and RS morbidity of the population of region taking into account rates of development of the cities, as well as changes in the quantitative characteristics of ozone dependent RS pathologies. Such studies combined with satellite data (in particular, the data Aura-OMI) and modelling offer opportunities for risk prediction of harmful effects of ozone on the health of the population of the cities in Ukraine.

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